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AIR DEFENSE SYSTEM SIMULATION AND ANALYSIS SUPPORT

Final Report

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30 June 1980

U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama 35809

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This Report provides a description of air defense system simulation and analysis support, primarily in the area of multipath modeling, provided for the U.S. Army Missile Command by M&S Computing, Inc.. The developmental status of a computer model to determine the multipath error in an antiradiation missile (ARM) seeker when operating against a surface-based radar is given, along with details of the planned future effort on this problem.

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PREFACE

This document is the final report on Contract DAAH01-80-M-0176, an analysis and simulation planning effort performed for the System Simulation and Development Directorate, U. S. Army Missile Command. The effort was performed during the period 3 March 1980 through 30 June 1980.

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I. INTRODUCTION

During the period from 3 March 1980 through 30 June 1980, M&S Computing, Inc., provided system engineering and analysis support for the planning of a hybrid simulation of the PATRIOT Missile System for the System Simulation and Development Directorate, U.S. Army Missile Command (MICOM), Redstone Arsenal, Alabama, under contract number DAAH01-80-M-0176. This effort was initiated by joint planning sessions with personnel attending from MICOM; Mitchell and Gaithier, Assoc.; Boeing; and M&S Computing. As a result of these sessions, individual tasks were defined for the participants. M&S Computing was assigned the task of analyzing existing multipath models and recommending a best multipath model based on test data from the White Sands Missile Range, New Mexico. The purpose of this document is to provide a brief summary of this task.

II. MULTIPATH MODELING FOR ARM SIMULATIONS

An antiradiation missile (ARM) seeker operating against a ground-based radar would likely be illuminated not only by the portion of the transmit beam pointing at the ARM but also by portions of the transmit beam reflected from the ground as well. This effect, called multipath, which is significant for low grazing angles, can cause errors in the ARM seeker angle tracking mechanism. The problem at hand is then to develop a new mathematical model, or to adapt an existing one, that would effectively model the aimpoint errors on an ARM seeker due to multipath effects while operating against various radar systems.

A survey of the literature has revealed several well-developed multipath models. These models, developed by various persons, [1-4] differ in the approach to the modeling of scattering from the surface. They use various methods to treat the cases of smooth, flat-earth specular reflections; smooth, curved-earth specular reflections; and rough, curved-earth specular and diffuse reflections.

These models, however, are almost always concerned with the classic monostatic radar case (a transmitter and receiver at the same point illuminating a passive target). Examination of these models has shown that much of their content may be retained for the case of a radar illuminating an ARM seeker. The existing models may then be modified to accommodate the ARM seeker case, accounting for such things as the differing antenna patterns of the transmitting radar and the receiving ARM seeker.

The digital computer implementation of the model would then be structured in such a way as to separate components of the multipath problem into sections such as radar transmitter effects, ground reflection effects, and ARM seeker effects. This would allow the multipath effects simulation to be used with various radar transmitter and ARM seeker combinations. Also, various multipath ground reflection models might be tested to determine which best predicts actual performance.

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1. D.K. Barton, "Low-Angle Radar Tracking," *Proc. IEEE*, Vol. 62, No. 6, June 1974, pp. 687-704.

2. G.C. Evans, "Influence of Ground Reflections on Radar Target-Tracking Accuracy," *Proc. IEEE*, Vol. 113, No. 8, August 1966, pp. 1281-1286.

3. P. Beckmann and A. Spizzichino, *The Scattering of Electromagnetic Waves from Rough Surfaces*, The Macmillan Company, New York, and Pergamon Press, Ltd., London, 1963.

4. S.O. Dunlap and B.E. Pope, *Digital Simulation of Monopulse Angle Tracking with Multipath Propagation*, Report No. RE-TR-72-9, U.S. Army Missile Command, Redstone Arsenal, Alabama, May 1972.

Work performed to date has centered around identifying the analytical components needed to form the overall model. The specular reflection geometry is best approached as in Kerr, [5] but with some changes as noted in the analysis presented in the appendix to this report. The digital computer application desired makes the exact solution of the specular reflection geometry equations easily available, negating the need for graphs of correction factors.

Specular reflection is given virtually identical treatment in all of the references examined. This should result in a reasonably straightforward choice of modeling technique, along the lines of those given in References 1 and 4. The diffuse reflection problem may be approached in several different ways, three of which are presented by Dunlap. [6].

Present plans call for implementing more than one of the methods of determining the diffuse reflection effects, with the results from each tested against experimental data.

Once appropriate models have been modified or developed, they may be implemented on a digital computer. Here they may be evaluated against data taken from the HAWK IPAR ARM/CM field test which was conducted at White Sands Missile Range, so that the fidelity of the models may be confirmed.

The procedure to be used in confirming the fidelity of the multipath model will include a comparison of the statistical characteristics of the seeker pointing error with the statistical characteristics predicted by the model. Also, the spectral characteristics of the seeker pointing error in the angle rate domain will be compared to that predicted by the model. The field test seeker pointing error will be evaluated in an effort to isolate error due to multipath effects from error due to other sources, such as glint, thermal noise, and vehicle dynamics. The error due to thermal noise can be minimized by operating in areas of high signal-to-noise ratio, glint error can be minimized by not using data obtained when the ARM is relatively close to the HAWK radar, and error due to vehicle dynamics can be removed by using only data taken during straight and level flight.

The CW portions of the HAWK IPAR ARM/CM field tests at White Sands Missile Range were observed so that first-hand information on the data acquisition process would be available for the confirmation process. Topological maps of the test area were also obtained so that significant changes in the terrain about the multipath reflection points could be noted.

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5. D.E. Kerr, *Propagation of Short Radio Waves*, McGraw-Hill Book Co., New York, 1951.

6. S.O. Dunlap, *Selected Tovics on Radar Multipath Simulation*, Report No. RE-76-18, U. S. Army Missile Command, Redstone Arsenal, Alabama, November 1975.

The first-hand information obtained should lead to a greater efficiency and accuracy in the confirmation effort, as well as an increased "intuitive feeling" for the multipath problem throughout the modeling process.

III. CONCLUSION

The result of the multipath modeling effort should be a confirmed digital computer implementation of a model that would effectively model ARM aimpoint errors due to multipath effects while operating against a surface-based radar system. The resulting computer program could then be integrated into a larger simulation involving many aspects of the ARM-radar scenario.

REFERENCES

1. Barton, D.K., "Low-Angle Radar Tracking," *Proc. IEEE*, Vol. 62, No. 6, June 1974, pp. 687-704.

2. Evans, G.C., "Influence of Ground Reflections on Radar Target-Tracking Accuracy," *Proc. IEEE*, Vol. 113, No. 8, August 1966, pp. 1281-1286.

3. Beckmann, P., and Spizzichino, A., *The Scattering of Electromagnetic Waves from Rough Surfaces*, The Macmillan Company, New York, and Pergamon Press, Ltd., London, 1963.

4. Dunlap, S.O., and Pope, B. E., *Digital Simulation of Monopulse Angle Tracking with Multipath Propagation*, Report No. RE-TR-72-9, U. S. Army Missile Command, Redstone Arsenal, Alabama, May 1972.

5. Kerr, D.E., *Propagation of Short Radio Waves*, McGraw-Hill Book Company, New York, 1951.

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APPENDIX

SPECULAR REFLECTION GEOMETRY

A considerable error is introduced into the determination of the specular reflection parameters such as path-length difference, grazing angle, and elevation angle when a simple plane earth analysis is used. To obtain more accurate values for these parameters, a spherical earth analysis is used. In this analysis, from Reference 5, the computation of these parameters requires that the point of reflection be known. This point is defined by the distances r_i and r_2 (Figure A-1). If z_1, z_2, and G_r are known, r_1 and r_2 can be found by solving the cubic equation,

$$2\ r_1^3 - 3\ G_r\ r_1^2 + \left[G_r^2 - 2\ a_e\ (z_1 + z_2)\right] r_1 + 2\ a_e\ z_1\ G_r = 0. \quad \text{(A-1)}$$

This equation has the formal solution,

$$r_1 = \frac{G_r}{2} + A \cos\left(\frac{\phi + \pi}{3}\right), \quad \text{(A-2)}$$

where the parameters A and ϕ are found by

$$A = \frac{2}{\sqrt{3}} \sqrt{a_e \left(z_1 + z_2\right) + \left(\frac{G_r}{2}\right)^2} \quad \text{(A-3)}$$

$$\phi = \cos^{-1}\left[\frac{2\ a_e\left(z_1 - z_2\right) G_r}{A^3}\right]. \quad \text{(A-4)}$$

The restrictions are that $z_2 \geq z_1$, and therefore $r_2 \geq r_1$. Also, A_e is the effective 4/3 radius of the earth and is 8493316 m or approximately $8.5(10)^6$ m.

Knowing G_r, the direct path, R, can be found from the law of cosines:

$$R = \left[(a_e + z_1)^2 + (a_e + z_2)^2 - 2\ (a_e + z_1)(a_e + z_2) \cos\left(\frac{G_r}{a_e}\right)\right]^{1/2}. \quad \text{(A-5)}$$

The elevation angle, θ, can now be calculated using

$$\theta = \frac{z_2 - z_1}{R} - \frac{r_2^2 - r_1^2}{2\ a_e\ R} - \frac{r_1}{a_e}. \quad \text{(A-6)}$$

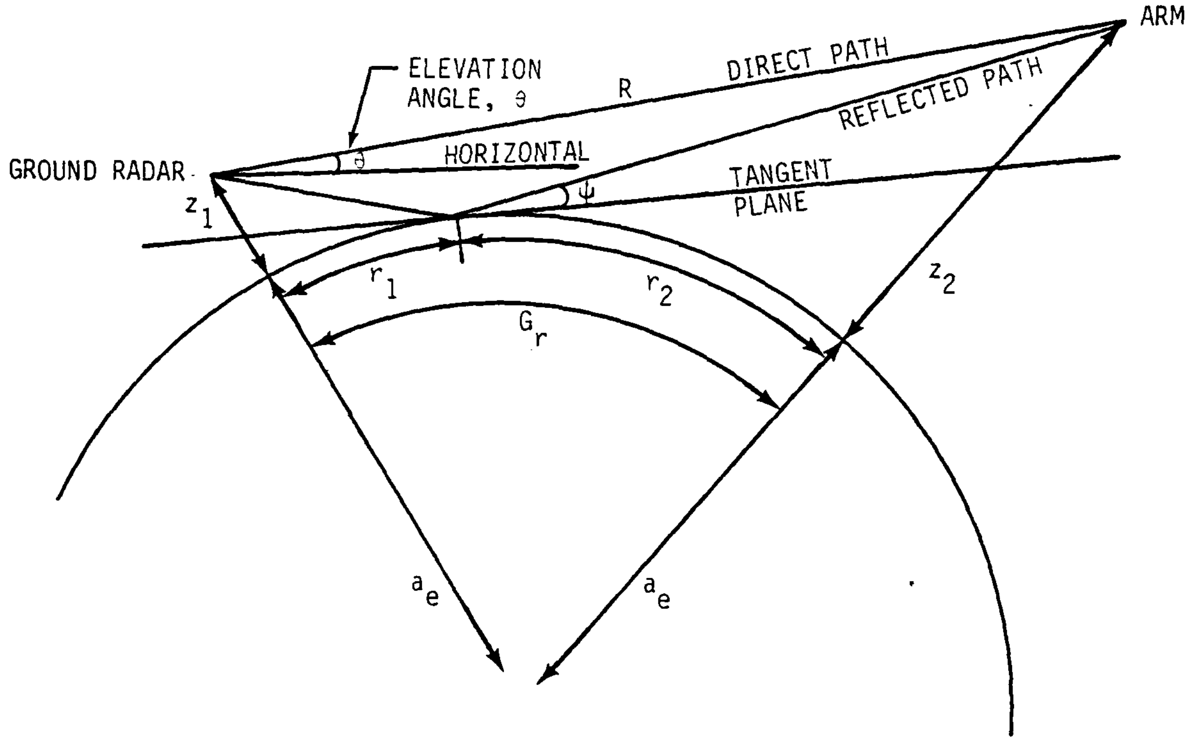

Figure A-1. Spherical earth specular reflection geometry.

From Reference 5, the equation for δ is

$$\delta = 2 \frac{z_1 z_2}{G_r} J(S,T). \tag{A-7}$$

Also, the grazing angle Ψ can be calculated by

$$\tan \Psi = \frac{z_1 + z_2}{G_r} K(S,T). \tag{A-8}$$

The parameters J(S,T) and K(S,T) are correction factors used to modify the plane earth geometry to the spherical geometry. J(S,T) and K(S,T) are found by the equations

$$J(S,T) = (1-S_1^2)\ (1-S_2^2) \tag{A-9}$$

$$K(S,T) = \frac{(1-S_1^2) + T^2(1-S_2^2)}{1 + T^2} \tag{A-10}$$

where

$$S_{1,2} = \frac{r_{1,2}}{\sqrt{2\ a_e\ z_{1,2}}} \leq 1 \tag{A-11}$$

and

$$T = \sqrt{\frac{z_1}{z_2}} \leq 1 \tag{A-12}$$

Also, the divergence factor, D, may be calculated by the equation

$$D = \left[1 + \frac{4\ S_1^2\ S_2\ T}{S(1-S_1^2)(1 + T)} \right]^{-1/2} \tag{A-13}$$

where

$$S = \frac{G_r}{\sqrt{2\ a_e\ z_1} + \sqrt{2\ a_e\ z_2}} \leq 1. \tag{A-14}$$

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